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The title of my talk is 'Enhancing the relationship between agriculture and the environment'. I will be talking about this very much from the perspective of an ecologist.

Principally, I would like to talk about the role of ecological field experiments in exploring how we can actually enhance this relationship. I am going to divide my talk into three sections. Firstly, should we be doing field experiments at all? There are certain sectors of opinion that feel we should not. Secondly, I would like to give a case study of how field experiments have clarified some issues, and then finally talk a little bit about where I feel we should be going in the future.

So first of all, Should we be doing field experiments at all? There is an idea that once we release these crops, they are irretrievable. Either the transgenic plants themselves are irretrievable, or the transgenes will escape into natural populations and these will be irretrievable. Escape is a two step process; gene flow, followed by establishment of those genes. Gene flow can be in the form of seeds of the crop, or pollen from the genetically modified crop hybridising with wild relatives. Gene flow will vary a great deal, depending upon environmental conditions, and depending upon which crops we are talking about.

At one end of the spectrum, we have maize, which has no wild relatives in this country, so gene flow will be fairly limited. At the other end of the scale, we have sugarbeet, which hybridises very readily with seabeet. Oilseed rape is intermediate, with some wild relatives with which it can hybridise, albeit relatively infrequently. However, even low rates of gene flow could result in establishment - so I am going to focus on this second step of escape.

We have an example here of a new road bridge in Scotland. Top soil was imported for the roadside verge, and the result is a population of oilseed rape growing alongside the road. This is not an uncommon site, but the question is, could such populations persist? Will the presence of certain transgenes make persistence more likely?

In this next slide are some relatives of oilseed rape, with which it can hybridise. Will their ecological fitness be altered by the presence of transgenes?

Ecological fitness has a very precise meaning which we can quantify. We take one point in the life cycle in successive generations: it could be seeds or seedlings, and estimate the ratio. This is the finite rate of increase, and if this is greater than 1 then the population will increase, if it is less than 1 then it will decline to extinction. We can go out into the field, simulate biological invasions under a range of ecological conditions and estimate the finite rate of increase. For example, this is an experiment in which oilseed rape seeds were introduced into a natural habitat. The range of ecological conditions was extended by experimental manipulations. The plants on the right are enclosed in a fence protecting them from vertebrate herbivory. In these plots, perennial plant competition was destroyed by cultivation. You can also manipulate fungal pathogen, insect herbivores, and other ecological factors. The key questions we are interested in are a) will ecological fitness ever be greater than 1?; b) will the genetically modified oilseed rape plants ever have greater ecological fitness than their conventional counterparts? We should also perform similar experiments with the hybrids produced between oilseed rape and its wild relatives.

Here are results from some early experiments conducted in the 1990s. The x axis marks the point where ecological fitness is equal to 1, so these histogram bars would need to be above the x axis for the population to be increasing. There are three points to notice. Only those populations in cultivated plots, where competition from other plants has been destroyed, have a finite rate of increase greater than 1. This is not a surprise, as crops are not designed to persist outside of cultivation. The second point to notice is that there is great variation from year to year. This illustrates one problem with ecological experiments - namely that they need to be conducted over a span of several years, as weather conditions and many other factors that affect the success of these plants are likely to vary temporally. Thirdly, this experiment was conducted with three genetic lines of oilseed rape, two of which were genetically modified. Under no conditions were the genetically modified varieties 'fitter' than the conventional varieties.

These results would be of no surprise to an ecologist, as it would not be expected that herbicide tolerance would confer an ecological advantage to a plant, outside the agricultural habitat in which they are being sprayed with the herbicide. But this does illustrate the sort of manipulative experiments we can do to investigate changes in ecological fitness.

Are there other genetically modified crops which may be of greater ecological concern? Here are two wild cabbage plants, a species which can hybridise with oilseed rape. The plant on the left has been infected with Turnip Yellow Mosaic virus while the plant on the right is healthy. So there are plant pathogens present in these natural communities which can have a great impact on fecundity of these wild plants. There are other pathogens which have a great impact on the survival of seedlings.

The question is, if we introduced transgenic resistance into these natural communities, would this release wild cabbage from the influence of its natural pathogens, causing wild cabbage populations to increase? This seems to be quite plausible as an ecological risk. However, we do need to place this in context. These kind of wild populations have evolved many resistance mechanisms to plant pathogens, and these plant pathogens have evolved ways of circumventing those resistance mechanisms. This has been referred to as the co-evolutionary arms race, and has been likened to the Red Queen in Alice Through the Looking Glass, who has to run faster and faster to stay in the same place.

Is there anything that might be different about genetically modified viral resistance? Well, possibly. This slide is a cartoon showing how transgenic viral resistance works. On the left we have a plant virus, with its genetic material surrounded by a protein coat. If a gene that codes for part of that protein coat is then inserted into the plant, so that protein is expressed in its leaves, then this can confer resistance to the viral pathogen. It is thought that these kind of resistance mechanisms could be rather more enduring than many produced by conventional varieties. While this is good news for agriculture, it could constitute an enhanced ecological risk. However, in terms of enhanced fitness, we do know what to measure, and how to go about measuring it.

Finally, I must again place this in context. If we are actually concerned about invasive alien plants, and there are a few hundred species of invasive aliens in the UK which have an adverse impact on biodiversity, the vast majority of them originate from our back gardens. The rhododendron is a good example of this. We import thousands of alien species for the purpose of growing as ornamental plants. These plants will be adapted to a wide range of conditions. On occasion, those conditions will be found in the UK. The plant will have been removed from many of its natural herbivores, and so has the opportunity to flourish in a suitable environment, without natural enemies. So, if we are concerned about invasive aliens we should be focussing our attention on horticulture.

So, to conclude for the first part of my talk, should we be doing experiments in the field? I feel that field experiments are the most effective way of assessing ecological risk. We need to focus on cases where ecological fitness may be enhanced, and the best assessment of invasiveness is by manipulative field experiments. Invasive aliens are a threat to biodiversity, but these mainly originate from horticulture.

For the second part of my talk, I would like to give you a brief overview of the debate surrounding the Monarch butterfly, which many of you will be familiar with. Maize crops grown in the US are conventionally subject to a very heavy pesticide regime. They do now also grow genetically modified maize, containing the insecticidal protein *Bacillus thuringiensis*, Bt. The other player in this story is the Monarch butterfly, something of a national emblem in the States. Its population is in decline - largely thought to be due to habitat loss at its overwintering sites.

The larvae of the Monarch butterfly feed exclusively on the milkweed plant, which can be found in and around maize fields. There was a very important study published in 199 in Nature, by Losey and colleagues, in which they showed that larvae which fed on milkweed leaves dusted with pollen from Bt maize showed enhanced mortality. After four days, nearly 50% had died. Now clearly this is a very undesirable unintended side effect.

This study raises more questions than it answers. These questions include: to what extent are larvae likely to be exposed to Bt pollen in the field? What is the phenological overlap between the larval feeding period and the production of maize pollen? What proportion of milkweed plants are actually found in maize fields, and how would mortality of larvae in crops of genetically modified maize compare with those in fields of conventionally treated maize?

A number of US ecologists have now done a substantial amount of fieldwork, both surveys and field experiments, to answer some of these questions. Here are some of the answers they have come up with. Most pollen falls very close to the maize fields and most milkweed actually grows in nature conservation areas which are quite distinct from the agricultural areas. There is not a significant phenological overlap between pollen production and the susceptible stages of larval feeding. They have also looked at the toxicity to other key butterfly species, and the Swallowtail for example has been found not to be susceptible. Other corn varieties are not so toxic. It depends to a certain extent to the degree to which the Bt is expressed in the pollen.

To conclude for this part of the talk, this study clearly raises some very important issues. We should strive to minimise any impacts on non-targets. Part of the way forward is through choice of variety and tissue specific expression and I will talk a little bit about that later. But correctly applied, these kinds of crops particularly when we are talking about crops subject to such heavy pesticide management regimes, could have the potential to contribute to the preservation of biodiversity. I think this particular case study also illustrates that it is incumbent on all the players, particularly the scientists, to communicate the full context of any scientific results to the public or else the credibility of scientists is going to be jeopardised.

Now the last part of my talk, I would like to turn some of the frequently asked questions on their head. I would like to ask what are the mechanisms behind changes in farmland biodiversity? In what ways could biotechnology play a role in countryside stewardship? Dan Chamberlain and colleagues at the BTO produced a very important and excellent study in the Journal of Applied Ecology last year where they quantified 31 different measures of intensification of agriculture, and examined their impact on bird populations. I am going to illustrate a couple of those factors here.

One of the often-quoted patterns is that we have over the last three decades switched from growing spring crops to autumn sown crops and this has removed fields of stubble over winter, which can be important feeding sites for many bird species. There has also been a very dramatic increase in the number of pre -emergence herbicides, insecticides and molluscicides used. Dan and his colleagues put all this information together to come up with a score of agriculture intensification which increases from 0 –6, and also they correlated this with an index of bird abundance and diversity. We can see that there is a very significant negative correlation, so this is clearly a suggestion that intensification of agriculture has led to declines in bird biodiversity, and Andrew in the next talk will be talking about this in very much more detail. So this study has highlighted this very significant negative association but it is also very frustrating because many of the factors are highly confounded with each other. Technological developments have led to many simultaneous changes in land management and what we really need to do is to tease apart the precise mechanisms that are causing these changes. For ecologists the way forward would be to do manipulative field experiments - though clearly it is very difficult to do the relevant field experiments on an appropriate scale to answer these sorts of questions. However, this is where we need to be putting some of our resources if we are really interested in determining the mechanisms behind these patterns.

The farm scale evaluations are one example of a manipulative experiment designed to determine the implications of a change in land management practice on farmland biodiversity. With conventional crops, pre-emergence herbicides are often used, and herbicide treatments are confined to the period of time before crop growth has really taken off. Once oilseed rape has started to grow, it is quite difficult to control broadleaved weeds without damaging the crop. However, with GM herbicide tolerant oilseed rape, the crop is resistant to broad spectrum herbicides, which allows spraying to be delayed. English Nature, the RSPB and other organisations were concerned that the introduction of GM herbicide tolerant crops could exacerbate the declines in biodiversity just described. This is because the herbicides used with these crops are broad spectrum, having the potential to kill a wide range of plant species. However, other groups believe that GMHT crops may be beneficial to wildlife, because stubble can be left until spring.

So what kind of impact will GMHT crops have on biodiversity? Well, the jury is still out, and this is exactly the kind of question we hope to throw light on. It could be that earlier in the season we have higher biodiversity, and this is a crucial time for nesting birds. However, the GM herbicide treatment may be so effective that very few weeds are actually setting seed at the end of the season, so over longer periods of time we might actually have a decline of biodiversity. This is precisely the kind of manipulative experiment we need to throw light on how different changes in land management will impact on biodiversity.

The second question is how can biotechnology integrate with ecology to enhance countryside stewardship? Now this very boring looking plant is *Arabidopsis*, which has now been entirely sequenced. This is going to lead into a much greater insight into how genes are regulated and expressed. This means that the next generation of modified plants can potentially be designed with much greater specificity and Phil mentioned this in his talk. We can have tissue specific expression; we may even be able to have induced defences. In other words the plant will only produce its insect toxins when it has been subject to a certain level of herbivore damage. So here there really is potential for biotechnology and ecology together to come up with some more precise and some more environmentally friendly solutions.

We do have a number of countryside stewardship mechanisms already in place. We are now subsidising farmers to replace hedgerows and to leave field margins unsprayed. So there is the potential that if we are growing crops with fewer pesticides, these can be used to compliment these sorts of schemes. We should also explore cross compliance between growing genetically modified crops and these kinds of countryside stewardship schemes.

So to conclude, I think we really do need to base our judgements on different land management regimes on scientific criteria. I have tried to illustrate a key role for manipulative field experiments in providing us with the information to do that. If we really do decide that biodiversity is at the centre of our concerns I think we should be optimistic, I think an integrated approach with biotechnology and ecology could prove to be a very profitable way forward and I think we could do something about addressing these declines in biodiversity over the next three decades. However science does not have all the answers. What levels of biodiversity do we aspire to? Many species of plants and insects are actually prevalent in the UK because of past land management practise. We need to decide how we are going to make value judgements between say, for example, the Skylark compared to a dozen beetle species. Which species are we going to focus on and why? However, I do feel we need to consider all the tools that we have in our toolbox to try and move forward in enhancing the relationship between agriculture and the environment. I would like to acknowledge friends and colleagues whose ideas have contributed to this talk.